HANDBOOK of PEST MANAGEMENT

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Overview and Management of Vertebrate Pests

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I. INTRODUCTION

Agricultural pest management has traditionally focused on arthropods, weeds, and pathogenic organisms. However, many vertebrate species (primarily wild birds and mammals) at one time or another require management actions to reduce conflicts with agricultural production. In fact, vertebrate pest problems appear to be increasing in the United States [25]; in large part because successful wildlife management and conservation programs, as well as land use changes, have allowed populations of many vertebrate species such as deer, geese, and blackbirds to expand. In a 1989 survey of American farmers, about half of all field crop producers reported wildlife-related losses that totaled $237 million annually [117].

Vertebrate pest management must be approached differently than traditional management of plant and invertebrate pests for four interrelated reasons. First, vertebrate species are sentient organisms with complex, adaptable, and often secretive behaviors. Second, the sociological aspects of vertebrate pest management are multifarious and emotional, particularly the polarized views of society regarding the killing and managing of wildlife species. Third, vertebrate pest species such as deer and Canada geese also are important economic resources because of their status as prominent game species. Finally, the regulatory aspects of vertebrate pest management are intricate, especially regarding the legal status of wildlife species (to be discussed in more detail below).

Vertebrate pest control programs can be thought of as having four parts: (a) problem definition, (b) ecology of the problem species, (c) control methods application, and (d) evaluation of control. Problem definition refers to determining the species and numbers of animals causing the damage, the amount of loss, and other biological and social factors related to the problem. Ecology of the problem species refers to understanding the life history of the species, especially in relation to the crop damage. Control methods application refers to taking the information gained from parts 1 and 2 to develop an appropriate management program to reduce the damage. Evaluation of control permits an assessment of the reduction in damage relative to costs and of the impact of the control on target and nontarget populations. Increasingly, emphasis is being placed on integrated pest management for vertebrates whereby populations are monitored and control methods are used in combination and coordinated with other management practices being used at that time (Fig. 1).

This chapter first reviews the legal status of vertebrate pests as related to crop protection. Second, methods of assessment and characteristics and amounts of crop damage caused by various avian and mammalian species are summarized. Examples of control techniques are then presented. Finally, managing blackbird damage to corn is discussed as an example of a plan that integrates the four components of vertebrate pest management outlined above. Scientific names of vertebrate species mentioned in the text are presented in Table 1.

II. LEGAL REQUIREMENTS FOR CONTROL

Before action is taken to manage vertebrate pests, it is important to understand the laws covering the target species. The management of most wild mammals, reptiles, and amphibians in the United States is the responsibility of the individual states. The capture, possession, or killing of these vertebrates to achieve control of damage is regulated by state laws. Migratory birds, in contrast to these other vertebrates, move freely across political boundaries and are thus managed at the federal level under the Migratory Bird Treaty Act of 1918, which is a treaty that has been amended several times and includes formal agreements with Canada, Mexico, Japan, and Russia. Federal regulations in the United States require that a depredation permit be obtained from the U.S. Fish and Wildlife Service, Department of the Interior, before any person may capture, kill, possess, or transport most migratory birds to control depredations. No federal permit is required merely to scare or herd depredating birds other than endangered species or eagles, but some states require permits for species such as waterfowl.

Introduced avian species in the United States such as house sparrows, rock doves (pigeons), and European starlings have no federal protection. Furthermore, a federal permit is not required to control blackbirds (the term *blackbird*

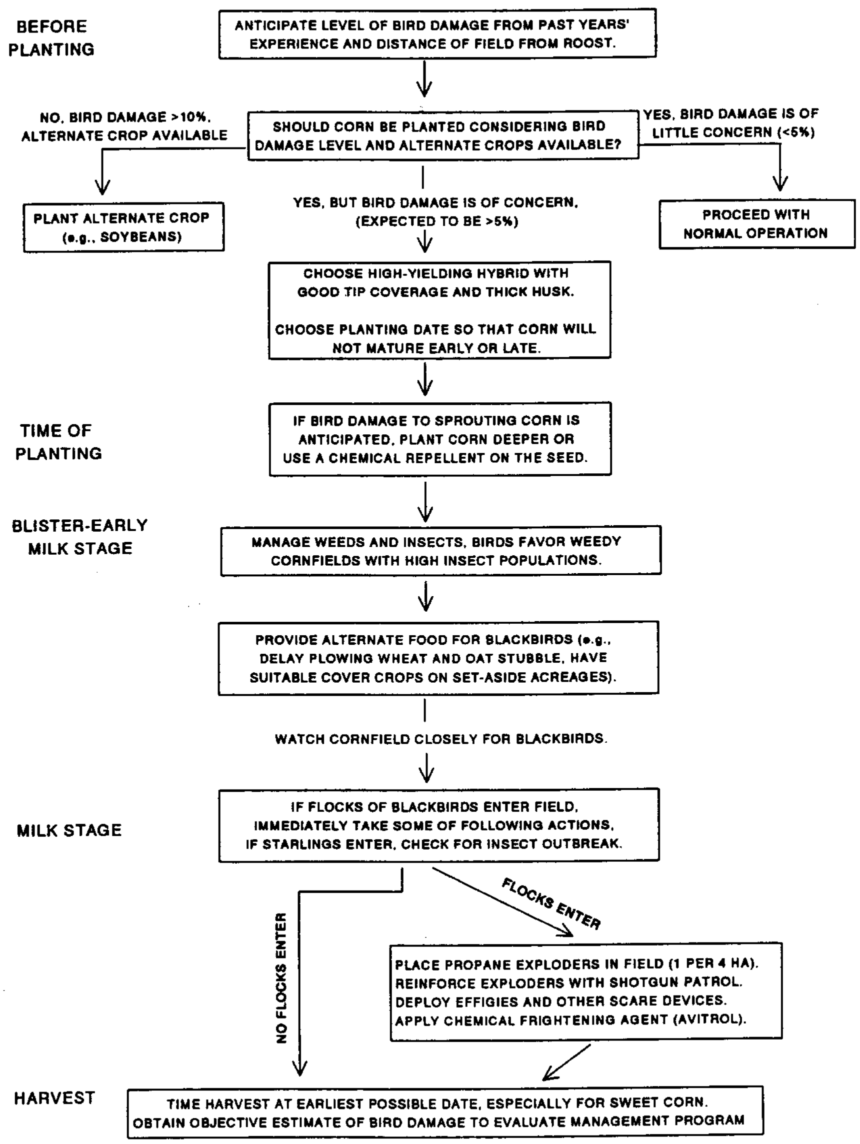

Figure 1 Schematic chart of integrated on-farm management program to reduce blackbird damage to corn. (Adapted from ref. 38.)

loosely refers to a group of about 10 species of North American birds, the most common of which are the red-winged blackbird and common grackle) when they are damaging or about to damage agricultural crops. However, federal provisions do not circumvent any state laws or regulations which may be more, but

Table 1 Common and Scientific Names of the Major Vertebrate Pest Species for Agricultural Crops in North America[a]

Common (scientific) name	Typical crop damage situations
Birds	
American robin (*Turdus migratorius*)	Fruit
Canada goose (*Branta canadensis*)	Winter wheat/sprouting soybeans
Common grackle (*Quiscalus quiscula*)	Sprouting and ripening grain/fruit
Duck (*Anas* spp.)	Ripening grain
European starling (*Sturnus vulgaris*)	Fruit/sprouting wheat/feedlots
House sparrow (*Passer domesticus*)	Ripening grain
Red-winged blackbird (*Agelaius phoeniceus*)	Sprouting and ripening grain
Rock dove (Pigeon) (*Columba livia*)	Sprouting grain/feedlots
Sandhill crane (*Grus canadensis*)	Sprouting and ripening grain
Snow goose (*Chen caerulescens*)	Winter wheat
Mammals	
Bear (*Ursus americanus*)	Ripening corn/apiaries
Beaver (*Castor candensis*)	Flooding cropland
Coyote (*Canis latrans*)	Melons
Deer (*Odocoileus* spp.)	Various crops/orchard trees
Ground squirrel (*Spermophilus* spp.)	Sprouting crops/range vegetation
Kangaroo rat (*Dipodomys* spp.)	Sprouting crops/alfalfa
Meadow vole (*Microtus pennsylvanicus*)	Orchard tree trunks
Mouse (*Peromyscus* spp.)	Sprouting no-till crops
Nutria (*Myocaster coypu*)	Sugarcane/rice
Pine vole (*Microtus pinetorum*)	Orchard tree roots/trunks
Pocket gopher (*Geomys* spp., other genera)	Various crops and trees
Prairie dog (*Cynomys* spp.)	Various crops and range vegetation
Rabbit (*Sylvilagus* spp.)	Sprouting crops/orchard trees
Raccoon (*Procyon lotor*)	Ripening corn
Roof rat (*Rattus rattus*)	Sugar cane/melons
Woodchuck (*Marmota monax*)	Sprouting and ripening crops

[a]See ref. 45 for an account of other vertebrate species that cause damage.

not less, restrictive. For example, Ohio law prohibits the killing of blackbirds damaging agricultural crops on Sundays.

In summary, anyone contemplating the capture or killing of a vertebrate species for damage control must first determine the state wildlife regulations for that species. For birds, federal wildlife regulations must also be followed. In addition, as with any pest control activity, federal and state Environmental Protection Agency (EPA) regulations must be followed whenever chemicals are used. Jacobs [63] provided a comprehensive list of EPA-registered chemicals for wildlife damage control in the United States.

III. METHODS OF ASSESSMENT, CHARACTERISTICS, AND AMOUNTS OF CROP DAMAGE

A. Methods of Assessment

Some pests, such as large flocks of blackbirds, are highly visible, and the damage they inflict in ripening grain fields is usually conspicuous. For these reasons, subjective estimates of blackbird damage sometimes overestimate losses as much as 10-fold [111]. However, rodent and ungulate (deer) damage to orchard trees or sprouting crops often occurs underground or at night by secretive animals, allowing losses to go unnoticed or to be underestimated. Thus, objective estimates of bird and mammal damage to agricultural crops are critical to define accurately the magnitude of problems and to plan appropriate, cost-effective control actions [39].

For many species of vertebrate pests, real crop losses are difficult to assess, because damage is usually highly variable among and within fields. Thus, to estimate losses, an unbiased sampling scheme is needed to select fields that are to be examined and then determine plants or areas to be measured in the selected fields [95]. For example, to estimate objectively the amount of bird and mammal damage in a ripening corn or sunflower field, at least 10 locations widely spaced in the field should be examined. At each location, the estimator should randomly select ears or heads from 10 plants to measure or visually estimate the amount of damage. This damage can then be converted to yield loss per hectare [35,37,116].

Losses of agricultural crops to birds also can be estimated indirectly through avian bioenergetics. By estimating the number of birds of the target species feeding in an area, the percentage of the agricultural crop in the birds' diet (obtained by examination of stomach contents from a sample of collected birds), the caloric value of the crop, and the daily caloric requirements of the birds, one can project the total biomass of crop removed by birds on a daily or seasonal basis [111,112].

Fruit loss to birds in orchards and vineyards can be estimated by counting the numbers of undamaged, pecked, and removed fruits per sampled branch or fruit bunch [34,103,105]. Pearson and Forshey [85] compared yield of apple trees visibly damaged by voles to those not showing damage to determine the dollar losses in gross return per tree. Richmond et al. [88] determined reductions in growth, yield, and fruit size of apple trees damaged by pine vole populations of known size maintained in enclosures around the trees. Forage and macadamia nut losses have been estimated by comparing production on areas with and without rodents [71,106].

An index of rodent damage to sugar cane was developed through sampling at harvest to determine the percentage of stalks damaged [68]. Clark and Young

[19] established transects in cornfields and noted rodent damage to individual seedlings over a 10-day period. Sauer [90] used exclusion cylinders to determine losses of forage to ground squirrels. Likewise, sprouting rice or other small grains removed by birds can be estimated by comparing plant density in exposed plots with that in adjacent plots with wire bird exclosures [82]. These loss estimates must be converted to accurate assessments of final yield reduction to enable cost/benefit evaluation of control programs. This conversion is often difficult given the complexity of factors that affect final yield [106,116].

These examples illustrate the complexity of damage situations and the need for better damage-assessment methods. Lack of methods for determining damage levels, particularly for rodents, has been a serious impediment to the development of cost-effective control strategies. Damage assessment methodology is an area of high priority for future research.

B. Characteristics and Amounts of Damage

1. Birds

Most bird damage occurs during daylight hours, and the best way to identify the species causing damage is by careful observation. However, the presence of a bird species in a crop receiving damage does not automatically prove the species guilty. For example, after careful observation and examination of the stomach contents of large, conspicuous flocks of common grackles in sprouting winter wheat fields, they were found to be eating corn residue from the previous crop. Smaller numbers of starlings were removing the germinating wheat seeds [49]. Conversely, flocks of starlings in ripening corn fields fed on insects, whereas flocks of blackbirds fed on the milk-stage grain [38]. Blackbirds characteristically remove the seed contents of the grain leaving the pericarp on the cob in contrast to deer and raccoons which remove the entire kernel (Fig. 2).

Birds annually destroy many millions of dollars worth of agricultural crops in North America. The greatest loss appears to be from blackbirds feeding on ripening corn; a survey in 1981 indicated a loss of 300,000 tons worth $31 million in the United States [5]. A follow-up survey in 1993 of all wildlife (bird and mammal) damage to ripening field corn indicated a loss of 860,000 tons, valued at $92 million, in the top 10 corn-producing states [118]. Blackbird damage to ripening sunflowers in the upper Great Plains states was estimated at $8 million in 1980 [61]. Damage by various bird species to fruit crops, peanuts, truck crops, and small grains also can be severe in localized areas [4]. For example, bird (primarily starling and robin) damage to blueberries in the United States and Canada was estimated at $8.5 million in 1989 [2].

Damage by ducks and sandhill cranes to swathed or maturing small-grain crops during autumn is a serious, localized problem in the northern Great Plains region [66]. Damage occurs from direct consumption of grain and from trampling, which dislodges kernels from heads [101]. Canada and snow geese grazing and compacting wheat and rye crops in winter can reduce subsequent grain and vegetative yields [24,65]. Canada geese also can be a serious problem to sprouting soybeans in spring and for fields of standing corn in autumn.

2. Mammals

Unlike birds, most wild mammals are secretive and not easily observed; many are nocturnal. Often the investigator must rely on various signs, such as tracks, trails, tooth marks, missing plant parts, scats (feces), or burrows to determine the species doing the damage. Traps may be necessary to identify positively small rodent species.

Characteristics of the damage may also provide clues to the species involved. In orchards, for example, major stripping of roots is usually caused by pine voles, whereas damage at the root collar or on the trunk up to the extent of snow depth is most often caused by meadow voles (Fig. 3). In sugar cane, various species of rats gnaw stalks so that they are hollowed out between the internodes but usually not completely severed. Rabbits, in contrast, usually gnaw through the stalks leaving only the ring-shaped internodes [68,69]. Unlike rodents and lagomorphs (i.e., rabbits), deer and other ungulates do not have upper incisors. Thus, twigs or plants nipped by these species may not show the neat, sharp-cut edge left by most rodents and lagomorphs but instead show a rough, shredded edge and usually a square or ragged break. Dolbeer et al. [45] presented a comprehensive description of damage characteristics by various mammal species.

Ungulate damage to various agricultural, forestry, and ornamental crops caused by feeding, trampling, and antler rubbing is an increasing problem [117], but objective estimates of economic loss are difficult to obtain. For example, losses in yield or tree value may accumulate for many years after damage occurs and vary with other stresses, including rodent damage, inflicted on the plants. In Ohio, growers reported average losses to deer in 1983 of \$204/ha for orchards, \$219/ha for Christmas tree plantings, and \$268/ha in nursery plantings [92]. Fruit and tree losses apparently are in the millions of dollars annually in some U.S. states [6,20,27]. With regard to row crops, Hygnstrom and Craven [62] estimated a mean loss to deer of 2680 kg of corn per hectare for 51 unprotected cornfields in Wisconsin. Yield reductions in soybean fields are most severe when deer feeding occurs during the first week of sprouting [33].

(a)

Figure 2 Damage to corn by (a) blackbirds and (b) raccoons can sometimes be confused. Blackbirds usually slit the husk and peck out the soft contents of kernels leaving the pericarp. Raccoons and squirrels chew through the husk and bite off the kernels. (Photographs courtesy of R. A. Dolbeer.)

Assessments of damage caused by rodents and lagomorphs, although limited, indicate that these mammals also cause tremendous annual losses of food and fiber in the United States. Forest animal damage in Washington and Oregon, primarily caused by rodents, was estimated to total $60 million annually to Douglas fir and ponderosa pine plantings, and the potential reduction in the total value of forest resources was estimated to be $1.83 billion [6,16]. Miller [79]

(b)

Figure 2 Continued

surveyed forest managers and natural resource agencies in 16 southeastern states and estimated annual wildlife-caused losses to timber and croplands, primarily caused by beavers, to be $11.2 million on 28.4 million hectares. An additional $1.6 million was spent to control wildlife damage on this land. Arner and Dubose [1] estimated that economic loss to beavers exceeded $4 billion over a 40-year period on 400,000 ha in the southeastern United States.

Rats cause substantial losses in sugar cane. Lefebvre et al. [68] estimated annual losses to be about $6 million ($235/ha) in one third of the area produc-

Figure 3 Meadow voles cause reduced apple production, and sometimes loss of trees, in orchards where they tunnel through snow and girdle trees by gnawing bark near the root collar and up the trunk as far as snow cover extends. (Photograph courtesy of M. E. Tobin.)

ing sugar cane in Florida. Hawaiian losses were reported to be in excess of $20 million per year [93]. Ferguson [55] estimated that in 1978, voles caused losses that approached $50 million to apple growers in the eastern United States. Losses of forage on range lands to rodents, rabbits, and hares are also extensive; however, accurate estimates of the monetary losses are difficult to obtain because of the nature of the damage and the wide area over which it occurs [72].

Mice can cause significant losses to corn seedlings in conservation tillage systems, but this damage may be offset by their consumption of harmful insects and weed seeds [19,64]. Ground squirrels, kangaroo rats, prairie dogs, nutrias, pocket gophers, and other rodents can also inflict serious damage to pastures, range lands, grain and bean fields, vegetable gardens, and fruit and nut crops. The burrows of some of these species can cause collapse of irrigation levees, increase erosion, and result in damage to farm machinery [74]. Carnivores such as raccoons and bears feeding on ripening corn [23,98] and coyotes on melons [54] can also cause substantial losses. Annual losses from these miscellaneous rodent and carnivore species are largely unquantified on regional scales but are likely to be in the $100s of millions nationally.

IV. DAMAGE CONTROL TECHNIQUES

A. Modifications of Habitat and Cultural Practices

Habitat and cultural modifications can be implemented in many situations to make roosting, loafing, or feeding sites less attractive to birds and provide long-lasting relief. For example, thinning marsh vegetation (cattails [*Typha* spp.]) can cause roosting blackbirds to move from agricultural areas where they are causing damage to sunflowers [70].

The use of lure crops, where waterfowl or blackbirds are encouraged to feed, is sometimes cost effective in reducing damage to nearby commercial fields of grain and sunflowers where bird-frightening programs are in place [29,100]. Provision of alternative foods (e.g., grain scattered on ground) may reduce loss of corn seedlings to rodents in no-tillage fields [64] and damage to apple trees in winter [102]. Davis [32] reported that pine vole damage in an apple orchard was reduced by mowing three times a year, clearing vegetation from under the trees, removing pruned branches, restricting the distribution of fertilizer, and inspecting and cleaning vulnerable parts of the orchard after harvest.

Bird-resistant cultivars of corn, sunflower, and sorghum have been effective in reducing damage. For example, cultivars of corn with ears having long, thick husks difficult for blackbirds to penetrate incur less damage than do cultivars with ears having short, thin husks [51,52]. Early-maturing cultivars of cherries are generally more susceptible to bird damage than late-maturing cultivars [104]. Planting grain crops so that they do not mature unusually early or late can also reduce damage by blackbirds [15]. Control of insects in corn fields can make those fields less attractive to blackbirds and reduce subsequent damage to the corn crop [42,115].

B. Proofing and Screening

Plastic netting is cost effective in excluding birds from individual fruit trees or high-value crops such as blueberries or grapes [56] (Fig. 4). Many different fence designs have been tested for excluding ungulates, including the 1.5-m Penn State Vertical Electric Deer Fence consisting of five strands of high-tensile steel wire (Fig. 5). Single-strand electric wire fences, 0.6–1.0 m high and baited with peanut butter to entice deer to contact the wire with their muzzles, have been cost effective in reducing damage in orchards and corn fields [62,87]. In England, wire netting and electrified netting fences have excluded rabbits from crop fields [75].

Figure 4 Nylon netting can be a cost-effective means of eliminating bird damage from high-value crops, such as in this vineyard on Long Island, New York. (Photograph courtesy of M. E. Tobin.)

Individual seedling protectors made of photodegradable plastics (e.g., VEXAR tubes; International Reforestation Supplers, Eugene, OR) are effective in reducing ungulate and rodent damage to young conifer trees [17,36]. In orchards, rabbit and aboveground rodent damage can be eliminated by wrapping trees with hardware cloth or burlap that is buried about 10 cm deep around the tree base [107].

C. Frightening Devices

Many devices are marketed, or homemade, to frighten birds and certain mammals such as deer. Target species usually habituate to such devices no matter how effective they may be initially. For example, deer habituated in less than 3 days to propane cannons used to protect piles of corn when the cannons were programmed to detonate systematically every 8–10 min. However, motion-activated cannons were effective for up to 6 weeks [3]. Two important rules are

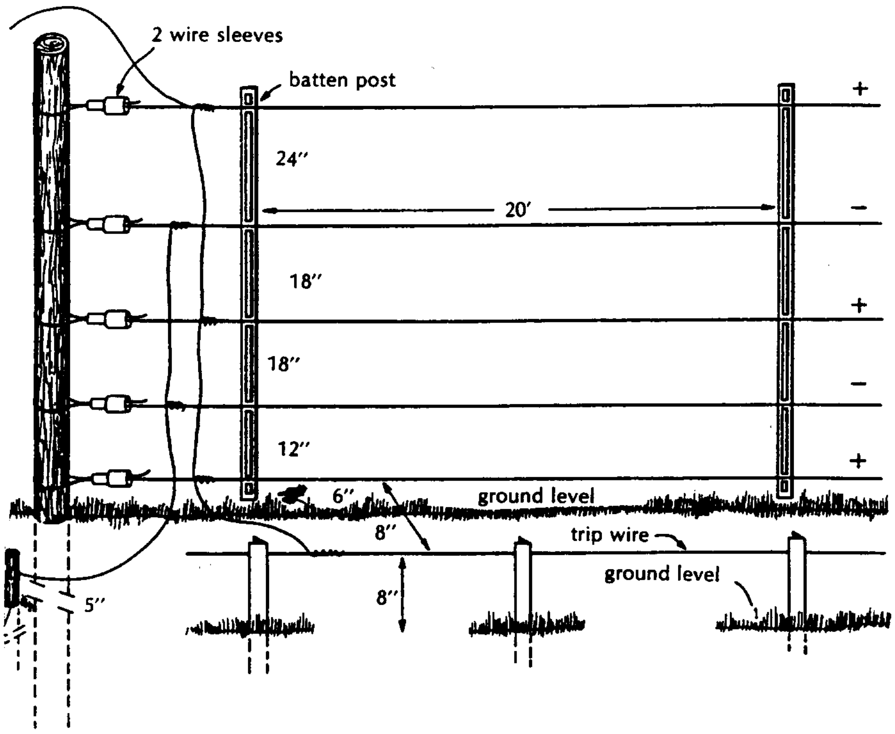

Figure 5 A 2-m high Penn State Vertical Electric Deer Fence. (From ref. 83.)

never to rely solely on one type of device for frightening and to vary the use of devices by altering the timing and location.

Probably the most widely used frightening device for birds and deer is the propane cannon (Fig. 6), which produces a loud explosion at timed intervals. Several models are marketed, including ones with automatic timers and rotating barrels. To be effective in frightening birds from crops, at least one cannon should be used for each 4 ha [30] and cannons should be moved every few days. An occasional shotgun patrol to reinforce the exploders is important for frightening birds [38], using either live ammunition or shell crackers. Shell crackers, fired from a 12-gauge shotgun, shoot a projectile that explodes 50–75 m away. Other pyrotechnic devices for frightening birds include rockets and whistle bombs [13].

Recorded alarm and distress calls of birds broadcast over a speaker system sometimes work well to frighten birds [12]. These calls are commercially avail-

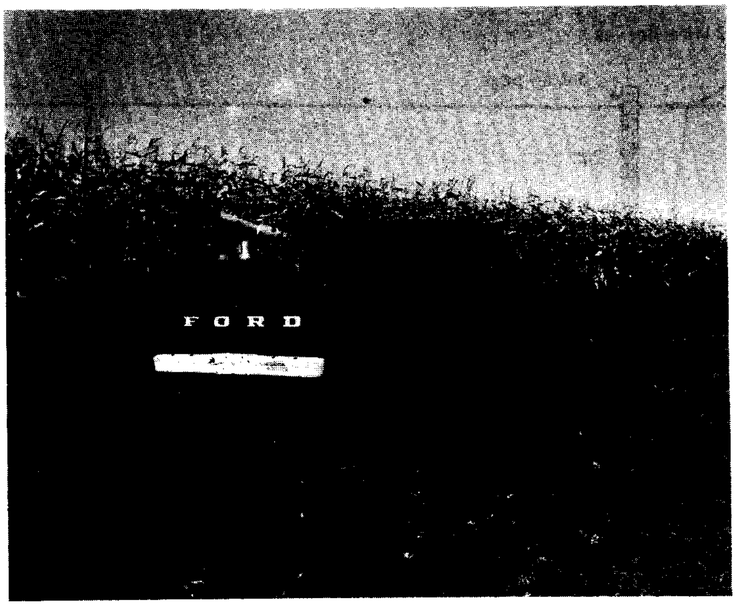

Figure 6 Propane exploders are often used to frighten birds, especially blackbirds, from corn and other crops. For best results, exploders should be elevated above the vegetation, moved around periodically, and occasionally supplemented with a shotgun patrol or other frightening device. (Photograph courtesy of R. A. Dolbeer.)

able for many birds species [91]. Shooting at birds with a shotgun is often used to reinforce the distress calls.

Ultrasonic devices emitting sounds with frequencies above the level of human hearing (20,000 hz) sometimes are marketed for bird control. However, objective field tests have not demonstrated effectiveness of ultrasonic devices in repelling birds [114]. Most birds detect sounds in about the same range of frequencies as do humans.

Flags, helium-filled balloons with and without eyespots, and hawk-kites suspended from balloons or bamboo poles have been used with some success to repel birds from small agricultural fields (e.g., see ref. 21). Mylar flags, 15 cm × 1.5 m in size, are used to keep geese from winter wheat, corn, and alfalfa. Ten flags per 4 ha are recommended [59]. Reflecting tape made of Mylar, strung in parallel lines at 3- to 7-m intervals, has reduced blackbird numbers in small agricultural fields [50] (Fig. 7).

D. Repellents

Numerous odor and taste repellents have been developed to reduce deer and rodent browsing on ornamental plants, fruit trees, and crops. High cost and

Figure 7 Mylar reflecting tape strung above the vegetation can reduce blackbird feeding activity in agricultural fields. (Photograph courtesty of R. A. Dolbeer.)

variable effectiveness during the growing season generally make mammal repellents impractical for use on low-value row crops such as corn [62]. Repellents are most effective on trees and shrubs during the dormant season, but results are inconsistent. Even under optimal conditions, some damage occurs (e.g., see 22,26, and 84).

Birds generally have a poorer sense of smell and taste than do mammals, and repellents based on these senses are usually not effective. One exception may be methyl anthranilate, a taste repellent that has shown effectiveness with birds [31]. In contrast to taste repellents, chemicals that produce illness or adverse physiological response upon ingestion (i.e., conditioned aversion) appear to work well as bird repellents [89]. Methiocarb, a carbamate insecticide, is a condition-aversive repellent that has been effective as a powdered seed treatment for corn [60] and as a spray treatment for ripening cherries, blueberries, and grapes [43]. However, methiocarb is not presently registered for bird control in the United States. There is a need for registered bird repellents, especially to protect sprouting grain and ripening fruits.

E. Shooting and Trapping

Shooting can be effective in reducing local populations of depredating birds if only a few birds are involved. Shooting has little effect on large numbers of birds other than the repelling value [80]. This concept has been promoted in Wisconsin through a hunter referral program in which farmers allow goose hunters to shoot in agricultural fields experiencing chronic damage [58].

The effective use of the hunting season to reduce populations of deer in areas of high damage is one of the best ways to control damage [27]. Some states also have special depredation permits that can be issued to a landowner to remove a specific number of deer at a problem site outside the normal hunting season if sufficient control cannot be achieved during the hunting season.

Various live traps have been used in attempts to reduce populations of starlings near cherry orchards [7] and blackbirds in areas of ripening rice [78] and corn [109]. As with shooting, these methods have generally been successful only when local, small populations of birds are involved [86]. Various live and kill traps are used to capture rodents and crop-damaging predators such as raccoons [45]. Again, these methods can be effective in reducing localized damage by small populations of pests. One important point with live trapping is that euthanasia, not relocation, is the preferred method of disposing of captured animals. Relocated animals, besides having poor chances for long-term survival, may spread diseases or parasites and create additional problems at the relocation site or in attempts to return home. Many states have developed restrictive policies for relocation of vertebrate pests.

F. Toxicants

The use of toxic baits and chemicals to kill pest birds and mammals in agricultural situations presently is greatly restricted compared to historic practices. As one recent example, the wetting agent PA-14 was registered by the U.S. Department of Agriculture for killing blackbirds and starlings in upland roosts from 1974 to 1992. During this time, over 38 million birds were killed to reduce agricultural damage and public health concerns [41,47], but PA-14 is no longer registered or being used. When mixed with water and applied by aircraft or ground spray systems to roosting birds, PA-14 allowed water to penetrate the birds' feathers, cooling the birds so that they died of hypothermia [96].

Two toxic baits still being used on birds in limited agricultural situations are DRC-1339 (USDA, Pocatello, ID) and Avitrol (Avitrol Corp., Tulsa, OK). DRC-1339 is incorporated into poultry pellets and marketed as Starlicide Complete for killing starlings at feedlots and poultry yards. DRC-1339 is also used in limited situations to kill blackbirds damaging sprouting rice [57]. The active ingredient of Avitrol, 4-aminopyridine, when ingested in small doses, causes affected birds to emit distress calls while flying in erratic circles. Affected birds usually die within 0.5 h, but their initial behavior can act to frighten other birds away [38]. In agricultural situations, Avitrol is registered for use on starlings in feedlots and for blackbirds in corn and sunflower fields.

Numerous rodenticide formulations are registered for use in commensal rodent control, around farm buildings, and in noncrop areas, but few rodenticides are registered for in-crop use [67]. Zinc phosphide, one rodenticide with limited in-crop uses, is relatively safe to humans, and its use usually does not result in secondary poisoning of nontarget species. The efficacy of zinc phosphide is poor or inconsistent on some field rodents but often can be improved by prebaiting and proper bait placement [73,107]. Development of registrations for in-crop use of rodenticides, particularly anticoagulants, is a high priority area for research.

Fumigants, another class of toxicants used in rodent control in agriculture, produce gases that are lethal when inhaled. They are placed into individual burrow holes to kill various fossorial mammals, such as pocket gophers, commensal rodents, prairie dogs, ground squirrels, and woodchucks [44].

V. INTEGRATED PEST MANAGEMENT: BLACKBIRD DAMAGE TO CORN AS AN EXAMPLE

As noted earlier, blackbirds feeding on ripening corn cause the greatest agricultural losses from birds in North America. This widespread problem, involving highly mobile, migratory birds with esthetic and other beneficial attributes, is generally not resolvable by direct reduction of populations or exclusion of birds from crops. Thus, damage-reduction programs based on the ecological relationship of blackbirds and the corn crop provide an excellent example of the types of integrated management efforts needed to deal with complex vertebrate pest problems (see Fig. 1). For an example of an integrated management scheme for mammalian pests (rodents in orchards), see Tobin and Richmond [107].

A. Population Ecology of Red-Winged Blackbirds

Red-winged blackbirds (hereafter referred to as redwings), being well adapted to agricultural land uses, are the most abundant bird in North America [47] and the principal avian pest of corn and other grain crops. The continental population, perhaps 165 million at the start of the nesting season in April, doubles to over 350 million birds by July when most young have fledged [46,77]. In July, redwings concentrate in nocturnal roosts containing up to several million birds, usually in marshes within 200 km of their nesting localities [40]. During the day, these birds forage, generally within 10 km of the roosts. The additional energy demands from feather molting [113] coincide with peak numbers of birds at the time the corn crop is ripening, setting the stage for economically significant damage to some corn fields (i.e., >5% yield loss) within 10 km of these late-summer roosts [10,38]. During autumn, after the corn is harvested, redwings and other blackbird species migrate to the southern United States [40]. Residue corn in harvested fields is an important food for redwings from winter [112] to early summer [18].

Environmentally safe reduction of redwing populations causing late-summer damage to corn and other crops has generally proven not to be feasible, both from a population dynamics perspective [41,46] and in practice [108]. Given the localized nature of the damage, the adaptations of redwings to the agricultural environment, and the beneficial attributes and legal status of these birds, population reduction as a routine management action, even if feasible, might not be desirable anyway. For these reasons, most research has focused on nonlethal approaches to reducing damage.

B. Managing Crops and Wetland Vegetation at Roost Sites

Because redwing damage to corn is generally a problem only within a few kilometers of late-summer roost sites, the first strategy to reduce damage is to plant alternate crops not fed upon by blackbirds, such as soybeans, in these high-damage areas. A second strategy is to disperse the large concentrations of birds by thinning the dense, wetland vegetation where the birds roost at night. Dispersing the large concentrations of birds from a single roost in an area of intensive agriculture into smaller concentrations in widely dispersed roosts may reduce overall damage [70].

C. Blackbird Feeding in Relation to Corn Maturation

If a decision is made to grow corn within a few kilometers of a late-summer blackbird roost, an understanding of redwing feeding habits is critical to effective damage management. Corn ear development begins about 60 days after planting when the pistillate flowers, with elongated styles commonly referred to as silks, form in leaf axils. About 15 days after silking (DAS), ears have developed to the point where kernels are in the milk stage and are first vulnerable to damage by birds. Sweet corn ears are usually harvested from 16–20 DAS, when the immature kernels still contain 70–80% water, so this crop is vulnerable to bird damage for only a few days. Field corn is vulnerable to loss for several more weeks as the kernels, accumulating biomass, go through the dough and dent stages of development before harvest (Fig. 8).

Redwings are commonly observed in cornfields near roosting sites during the 2 weeks between silking and initial kernel development. No ripening corn is available in the fields for consumption at this time but insects, such as corn rootworm beetles (*Diabrotica* spp.) and the European corn borer (*Ostrinia nubilalis*), are often abundant. Several studies confirmed that redwings are initially attracted to corn fields in the silking period to feed on insects, and that

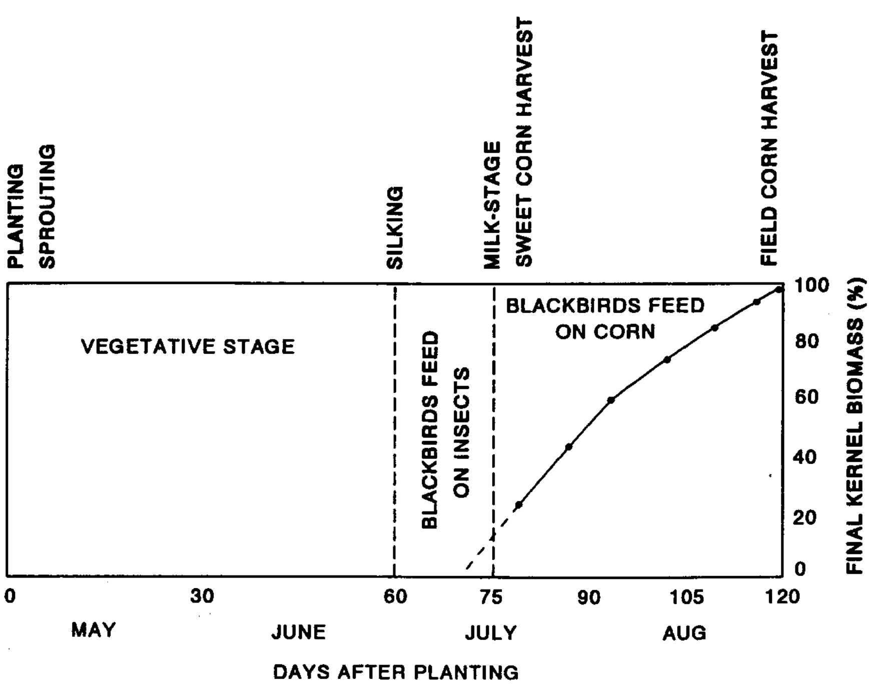

Figure 8 Chronology of typical sweet or field corn planting in midwestern United States showing feeding patterns of blackbirds and rate of biomass accumulation in corn kernels. (From ref. 116.)

control of insects with insecticides can subsequently reduce bird damage to ripening kernels [9,81,94,99,115]. Redwing feeding on beetles during silking in corn fields near roosts may be sufficient to offset some of the subsequent damage caused by feeding on kernels [11].

At the end of the silking period when kernels enter the milk stage, feeding by redwings on insects declines sharply as the birds switch to corn (Table 2). Most damage (kernels eaten) occurs during the milk and early dough stage of kernel development (16–30 DAS) [8,14,53] when kernels have little biomass. For example, kernels contain only about 25% of their final biomass at 20 DAS compared with 70% at 40 DAS (see Fig. 8). Thus, a flock of birds in a field must damage about three times as many kernels at 20 DAS as at 40 DAS to obtain the same corn biomass.

One obvious management implication for sweet corn is that the timing of harvest can have a dramatic influence on the level of bird damage. Damage can increase rapidly once kernels enter the vulnerable milk stage. Advancement of harvest by only 1 day can result in substantially less damage [38], especially if

Table 2 Food (aggregate % volume of gut contents) of Red-Winged Blackbirds Collected in Corn Fields During the Predamage Period and in Corn Fields (New York) or at a Nighttime Roost (Ohio) During the Damage Period

	Predamage (silking) period		Damage (kernel maturation) period	
Food	New York[a] (n = 21)	Ohio[b] (n = 17)	New York[a] (n = 84)	Ohio[b] (n = 66)
Rootworm beetles	59	33	4	<1
Other arthropods	8	35	6	6
Corn	19[c]	23[c]	89	88
Weed seeds	0	6	0	5
Other	14	3	1	1

[a]Data from Bollinger and Caslick [9].
[b]Data from Okurut-Akol [81].
[c]Mature kernels gleaned off of ground from previous year's harvest.

combined with insect control in the silking period to reduce the initial attractiveness of sweet corn fields to birds.

For field corn where damage occurs over a longer period of kernel development, the adjustment of harvest date is less effective in reducing damage. Nonetheless, protective measures to reduce damage (to be discussed below) are more critical in the early stages of kernel development (i.e., 15–30 DAS) than later, because the damage potential is much higher at this time. In addition, bird damage during the early maturational stages is more likely to lead to secondary damage (fungal, insect, sprouting) of kernels than is damage at later stages [116]. Thus, bird numbers being equal, a farmer will obtain a much greater return from his or her efforts by protecting field corn from damaging flocks during the milk stage of maturity than during later stages, Cummings et al. [28] noted a similar pattern of blackbird damage in ripening sunflowers.

D. Cultivar Resistance to Reduce Damage

An ideal resolution of the conflict between corn farmers and redwings would be to couple the beneficial feeding habits of the birds in silking-stage corn, as outlined above, with management techniques to reduce damage once corn enters the milk stage. One means of reducing damage is through the use of cultivars resistant to attack by birds. Aviary and field testing has established that sweet and field corn cultivars with long, heavy husks receive less bird damage than short, thin-husked cultivars [51,52]. In addition, cultivars with an extended period of vulnerability due to variation in maturity among plants are likely to have greater losses to birds than cultivars with synchronized, rapid ear development among plants [110]. No cultivars tested have been completely resistant to damage. However, certain cultivars do have consistently less damage than others, even in no-choice regimens in aviary tests that are more severe than field situations, where birds would always have alternative food sources such as weed seeds and insects. As a corollary, management of the habitat within the birds' foraging range surrounding roosts to provide alternative feeding areas should enhance the effectiveness of resistant cultivars. This will be discussed more fully below.

E. Bird-Frightening Techniques to Reduce Damage

Conventional bird-frightening techniques, such as propane exploiters, hawk-kites and other effigies, shooting, reflective ribbons, and Avitrol can all be of assistance in reducing redwing damage to corn [21,30,38]. The deployment of these devices when corn is most vulnerable to damage, as discussed above, is critical to their success. Their effectiveness should also be enhanced when used in fields of resistant cultivars. One caveat in the use of frightening techniques is that labor and material costs for their proper deployment are often relatively high, and careful assessment of expected benefits in relation to costs is needed before deployment [39].

F. Alternative Foods

The final component of an integrated management program involves the provision of alternative foods outside the corn fields but within the birds' daily foraging range from the roost. The basic tenet is that if the techniques discussed above are to be successful in discouraging birds from feeding in cornfields once kernels enter the milk stage, alternative feeding sites must be available. This hypothesis is supported by a study where blackbird damage to corn was highest in areas of least agricultural diversity [97].

There are numerous opportunities for providing alternative feeding areas in late summer. For example, oats and wheat are typically harvested at the time corn enters the silking stage. Delayed plowing of the stubble until after the corn harvest permits redwings to feed on the waste grains [76], reducing feeding pressure on corn. Delayed plowing of early-harvested sweet corn fields can also serve this purpose. The provision of natural and planted plots of wildlife food crops on wildlife refuges and on areas of farms set aside in price-support programs should also be beneficial. Such "lure crops" have been used for years to reduce waterfowl damage to maturing small-grain crops [66] and have shown promise for reducing redwing damage to nearby commercial sunflower fields [29].

VI. CONCLUSIONS

Vertebrates will be an increasingly important component of pest management in agricultural crops as long as successful wildlife conservation programs are continued among agricultural lands. Much work needs to be done, especially in refining our abilities to estimate costs and benefits associated with vertebrate species that damage agricultural crops and in further refinements of control strategies. However, important steps have been taken in achieving this goal for many species and the future for resolving conflicts appears bright.

Progress must continue in finding ways to accommodate wildlife as a part of agricultural ecosystems so that people can enjoy the positive attributes while simultaneously managing the pest species and crops to reduce damage to tolerable levels. Management techniques include improved abilities to predict when, where, and how much loss will occur so that control is undertaken only when necessary; selective population reductions through hunting and other means; cultural practices such as damage-resistant crops, timing of harvest, and manipulation of attractants; the use of physical barriers and repellents; proper timing in the deployment of frightening devices; and provision of alternate feeding areas. None of these techniques used alone will be sufficient; success will be achieved when they are used together in coordinated programs built upon a foundation of knowledge about the relationship of the vertebrate pest and agricultural crop.

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